

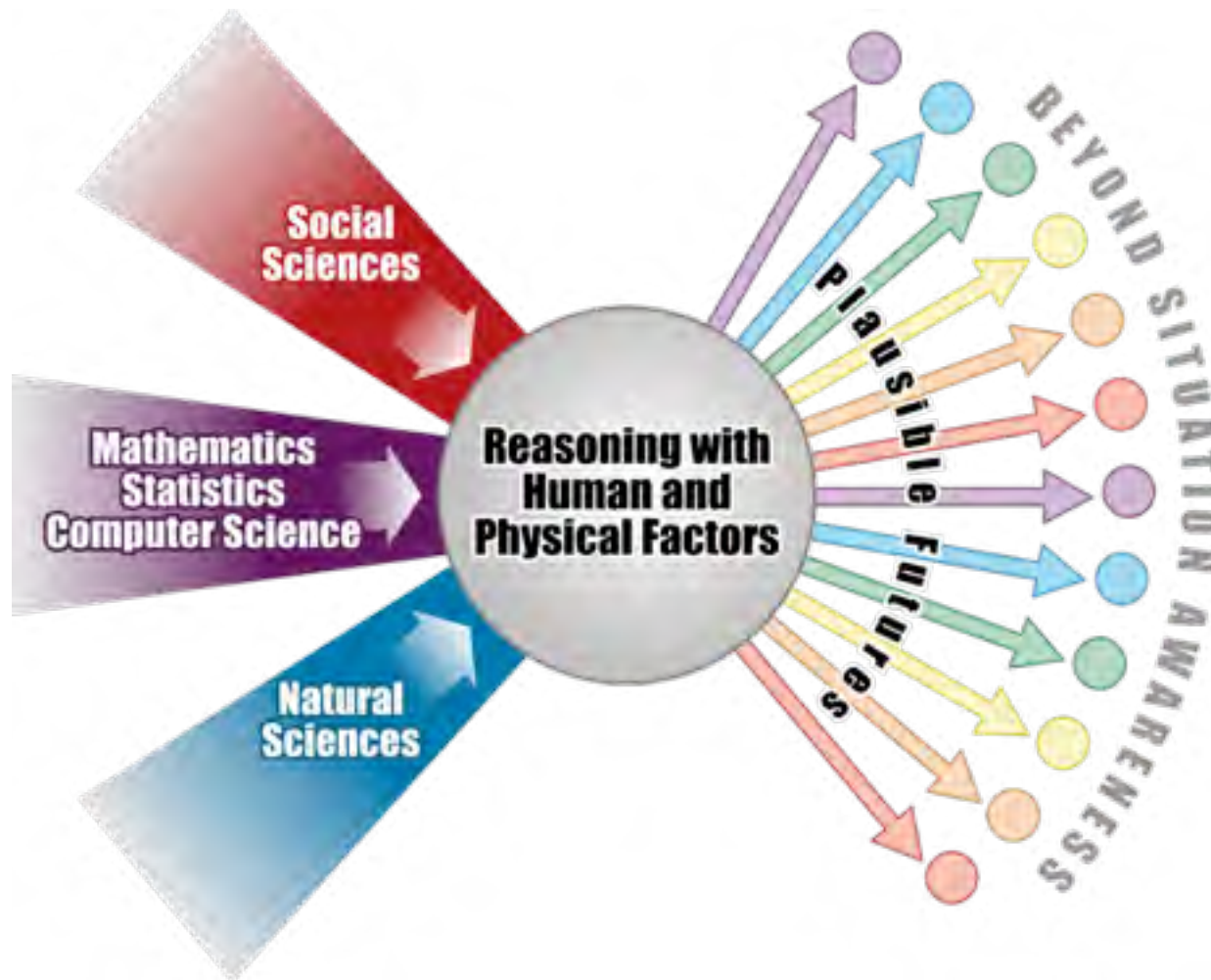
# Human Behavior and Energy Use: Modeling the Relationships

T. Sanquist, B. Shui, H. Orr, G. Gelston

“People, not machines, make the decisions that affect energy use. Insight into the human dimension of energy use is key to better understanding future energy trends and how to act effectively to manage them.”

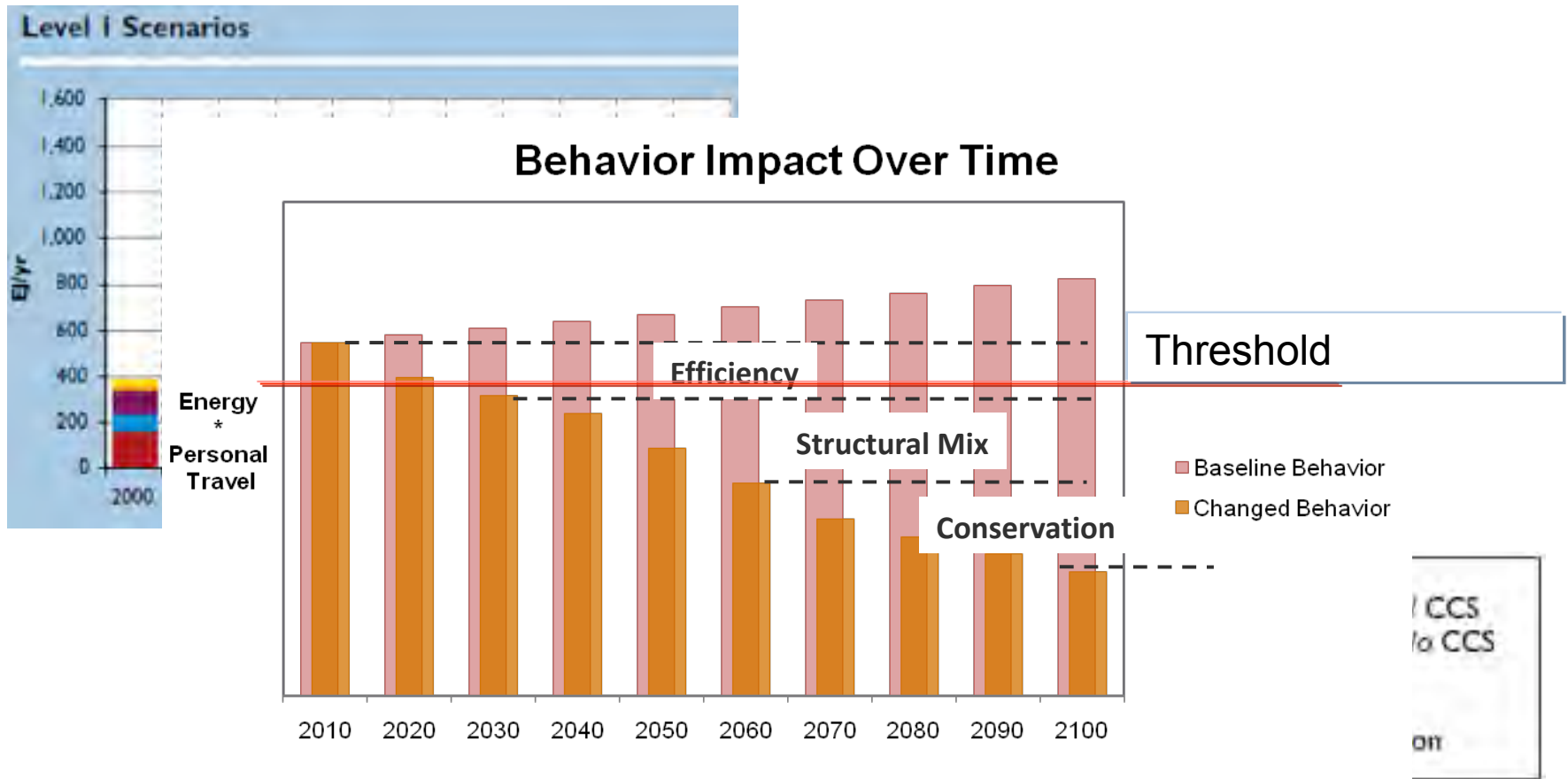
Schipper and Meyers, *Energy Efficiency and Human Activity*.  
Cambridge: Cambridge University Press, 1993.

# Techno-social Predictive Analytics Initiative (TPAI) – National Security Directorate LDRD



- ▶ Focus: tools for analysts emphasizing visualization
- ▶ Impetus: social network analysis applied to radicalization
- ▶ Other foci: IEDs, power grid vulnerabilities, regional impacts of climate change
- ▶ Energy security
  - How to ensure we have enough
  - What is sufficient?

# Goal: Behavior Change Prediction in Relation to Climate Change Stabilization



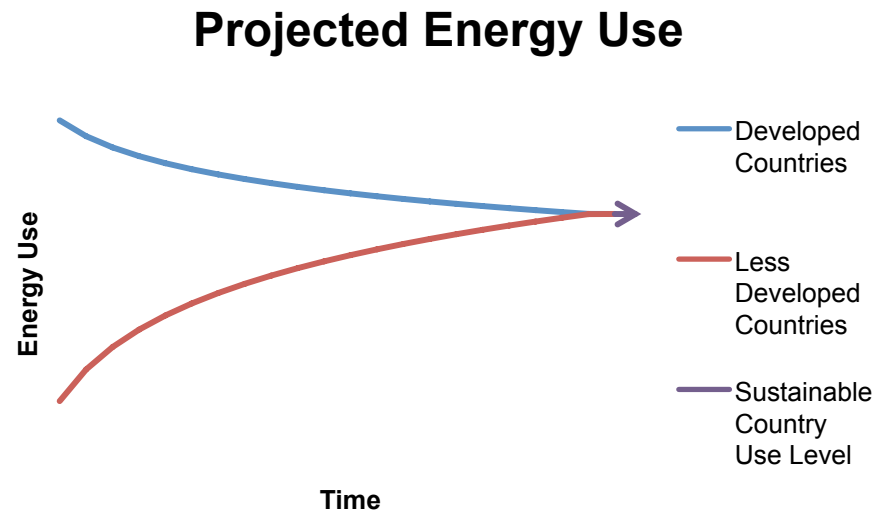
- ▶ Develop engineering model of relationships between GHG reduction, policy options, behavioral & social effects
- ▶ Quantify the “social-behavioral wedge” (Deitz, et al., 2009; Pacala & Socolow, 2004)

# Overview

- ▶ Background, Conceptual Issues, Methodological Approaches
- ▶ Current tasks and results
- ▶ General research needs
- ▶ Future tasks

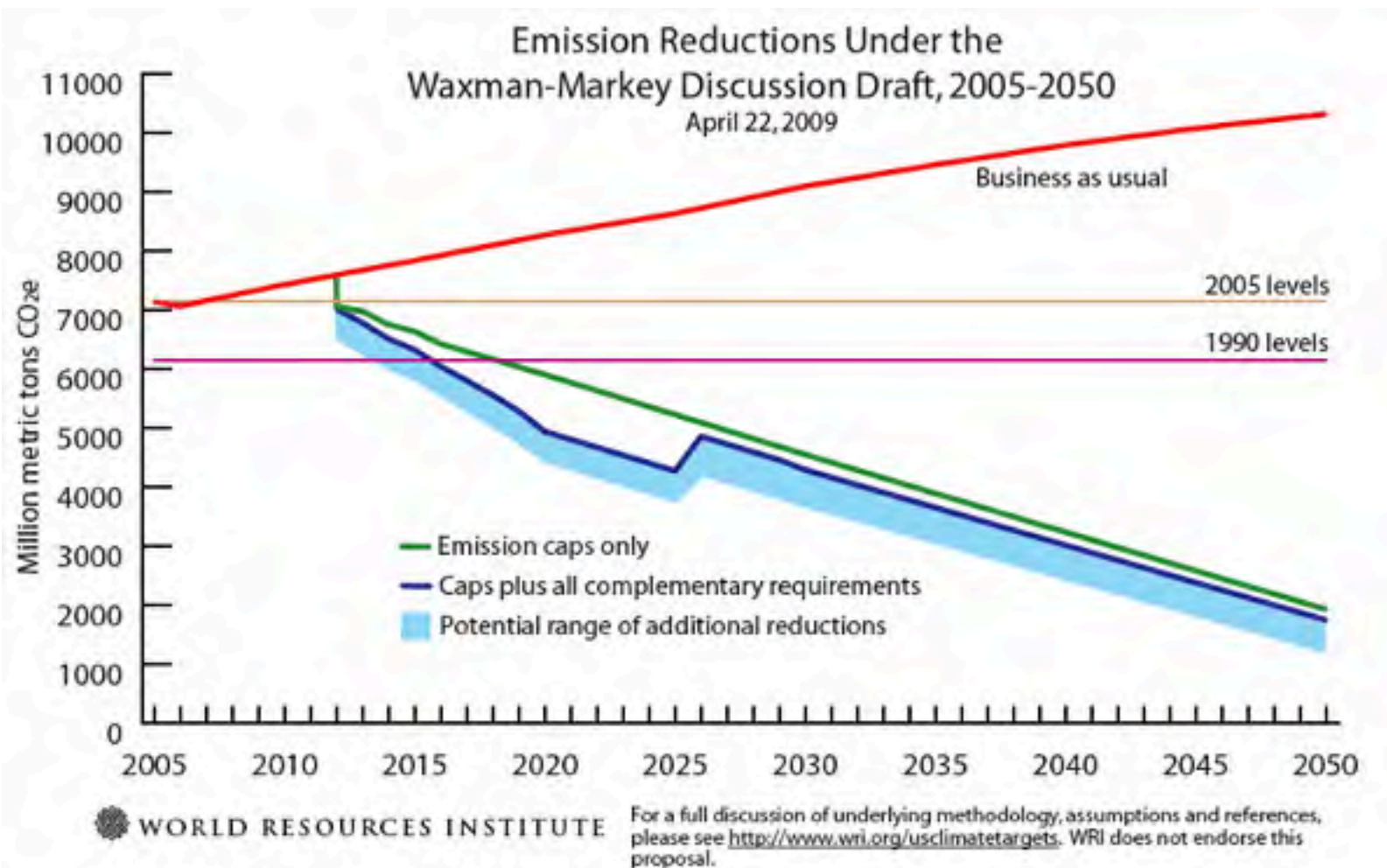
# Mission & Vision

- ▶ International stability depends on agreeing on climate change targets and successful implementation
- ▶ Develop behavioral-energy use prediction model to help understand how carbon caps will be achieved internationally
  - Developed nations will need to reduce
  - Less Developed Countries need to aim for sustainable development
- ▶ Stabilization will directly affect many aspects of everyday life – understanding behavioral impacts and influences is essential



# DOE Programmatic Funding 2009

- ▶ National Lab Consortium, including PNNL, to develop social science R&D agenda and framework.
  - Goal: identify social science contribution to meet challenge of climate change
  - How do we conduct R&D, policy and implementation to address?
    - What are impacts of policies such as tax credits, carbon caps?
  - Develop conceptual framework on scale from individual households to organizational and societal
  - Coordinate with other stakeholders to make specific contribution to stabilizing GHG at necessary levels
  - Interfaces between land use/urban planning, infrastructure development, impacts on groups and individuals

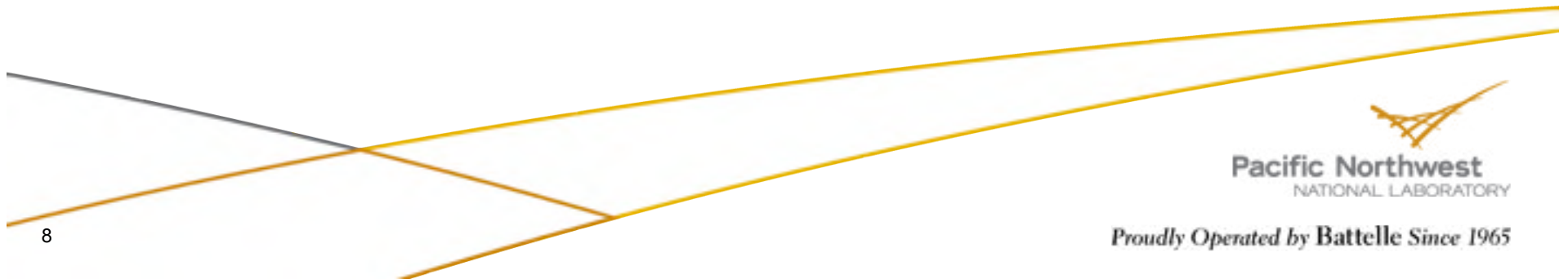


Social Scientist view: What behaviors map to the y-axis? Commute mileage? Thermal comfort? Delayed gratification? Miles walked/biked versus driven? Electronic proliferation reduction? International cooperation?



# Social Science engagement in energy policy and research

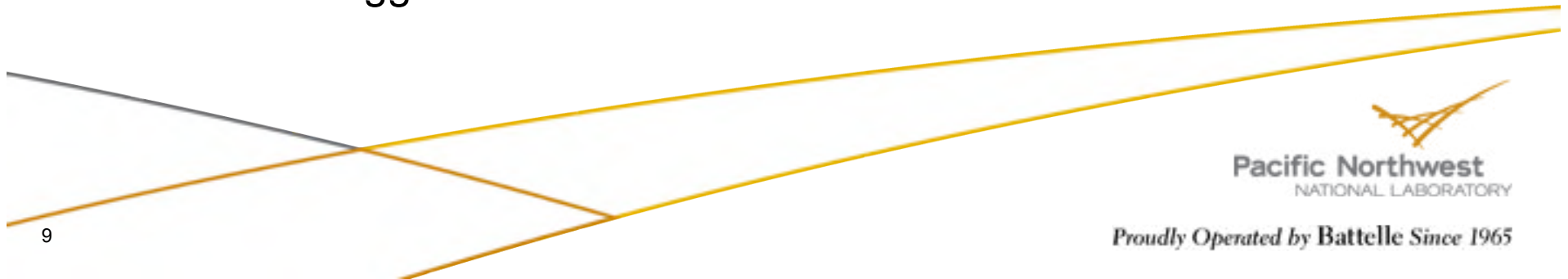
- ▶ Substantial activity in 1970s – mid 1980s.
- ▶ Change in focus in 1990s to Demand Side Management
  - Policy focus narrowed to “least cost energy supply”
  - Equating efficiency and conservation obscures important variables
- ▶ Energy policy has viewed human behavior as distinct from devices and socio-technical systems
- ▶ In practice, they are inextricably linked
- ▶ Need social view of energy use that involves multidisciplinary approach: history, urban/land use planning, architecture, sociology, economics, psychological disciplines



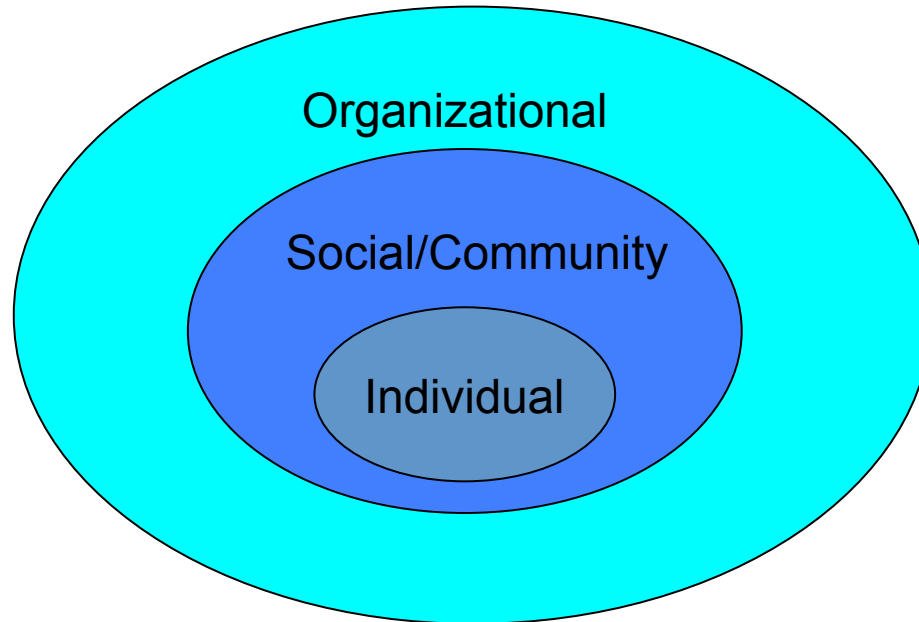


# National Security Implications, continued

- ▶ National security challenges (Climatic Cataclysm: The foreign policy and national security implications of climate change. Brookings Institute, 2008).
  - Expected climate change – 2.3°F by 2040
    - US as first responder
    - Immigration pressure
    - Loss of basing capability
  - Severe Climate Change – 4.7°F by 2040
    - Regional nuclear war potential
    - Border issues
  - Catastrophic Climate Change – 10.8°F by 2040
    - Struggle for survival



# Background – levels of behavior



- ▶ “Consumer choices about comfort (and convenience) are strongly influenced by changes in the built environment, which in turn have been favored by powerful commercial actors...including the energy industry, construction and banking industries.” (Wilhite, 2008)
- ▶ Changes in building practices worldwide have been the result (lack of passive cooling capability, for example)
- ▶ Changes in human expectations of thermal comfort

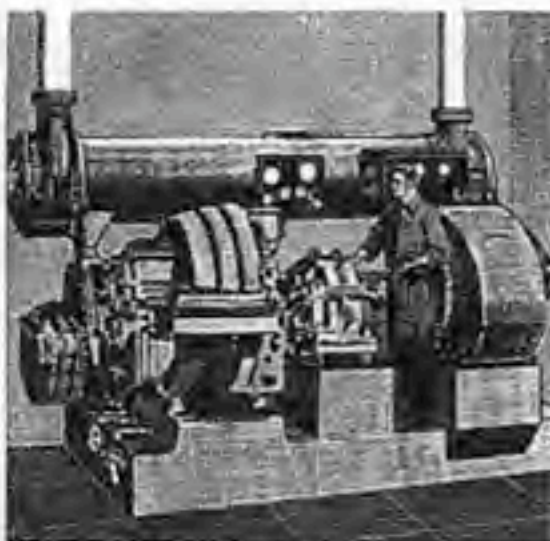


## UNCONDITIONAL SURRENDER

In Calcutta or Cairo, New York or New Orleans—wherever temperature soars and humidity is high, men suffer without air conditioning. They wilt and lose their drive. Whether they realize it or not, they are paying for the comfort air conditioning can bring—without enjoying it!



This punka is typical of man's attempts to tame torrid weather. Like other fanning devices, however, it only circulates. It doesn't cool, clean or wring humidity out of air. Only modern air conditioning can do the whole job — and do it well!



The Centrifugal Refrigerating Machine is one of Carrier's many "firsts" in air conditioning. It is the heart of the famous Carrier Conduit Weathermaster System providing perfect indoor climate for multi-room buildings, with individual control in each room.



You'll find new zest living or working in hotels, skyscrapers, ships, factories or apartment buildings completely air conditioned by Carrier. And there are attractive, compact Carrier Room Air Conditioners at low cost for your office and your home.



#### AIR CONDITIONING • REFRIGERATION

*The name "Carrier" stands for the finest engineering and the finest equipment money can buy. Call your Carrier dealer, listed in the Classified Telephone Directory, or address Carrier Corporation, Syracuse, N. Y.*



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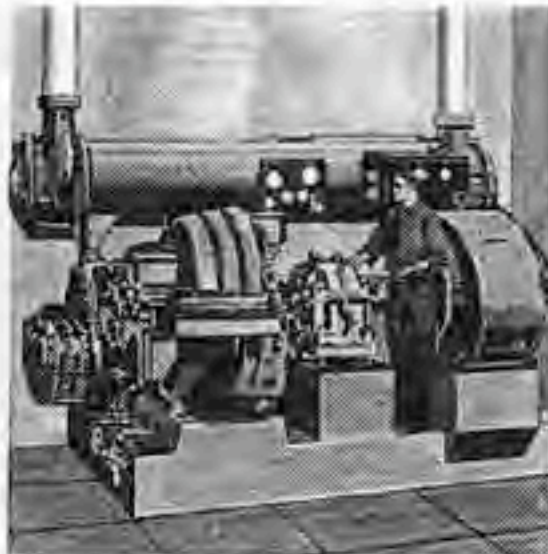


## TEMPERATURE 102°—PRODUCTION 0

Why have most great inventions and advances in science and industry come from temperate zones? Because for centuries tropical heat has robbed men of energy and ambition. There was no air conditioning. So they took siestas, seeking relief from heat and stifling humidity.



Ancient despots tried to beat the heat with fan waving. Slaves made this a cheap way to keep air in motion, but without modern air conditioning nothing could be done to remove humidity. Nor could fans filter dust, pollen, other impurities.



Healthful indoor weather — that's what this Carrier-developed centrifugal refrigerating machine gives man the world over. It is the heart of air conditioning systems providing comfort to hundreds of hotels, office buildings, stores, steamships.



Dining out is a real pleasure when cool, clean, refreshing weather in the restaurant is furnished by Carrier. And there is a type of Carrier Air Conditioning to give you the same bracing climate in retail shops, in your office and your home.



#### AIR CONDITIONING • REFRIGERATION

The name "Carrier" stands for the finest engineering and the finest equipment money can buy. Call your Carrier dealer, listed in the Classified Telephone Directory, or address Carrier Corporation, Syracuse, N. Y.

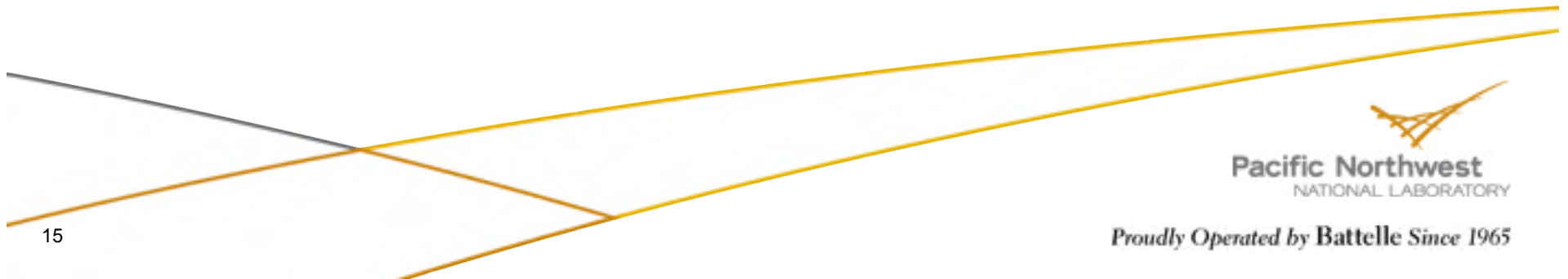


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# A/C Paradox

- ▶ Recent energy crises have led to specific demand reduction programs to reduce A/C use at peak periods
- ▶ Comfort technology leads to suffering





# Problem- General Issues

Extensive physical and economic modeling of climate impacts but lack of predictive modeling on behavioral side.

There is a lack of understanding regarding potential impacts of policy or regulatory interventions on economics and consumer lifestyle.

Energy use continues to outpace efficiency gains (the efficiency paradox). Both must be addressed.

The largest impact on GHG emissions in the next 20 years will come from efficiency and conservation (Chu, 2009)<sup>1</sup>

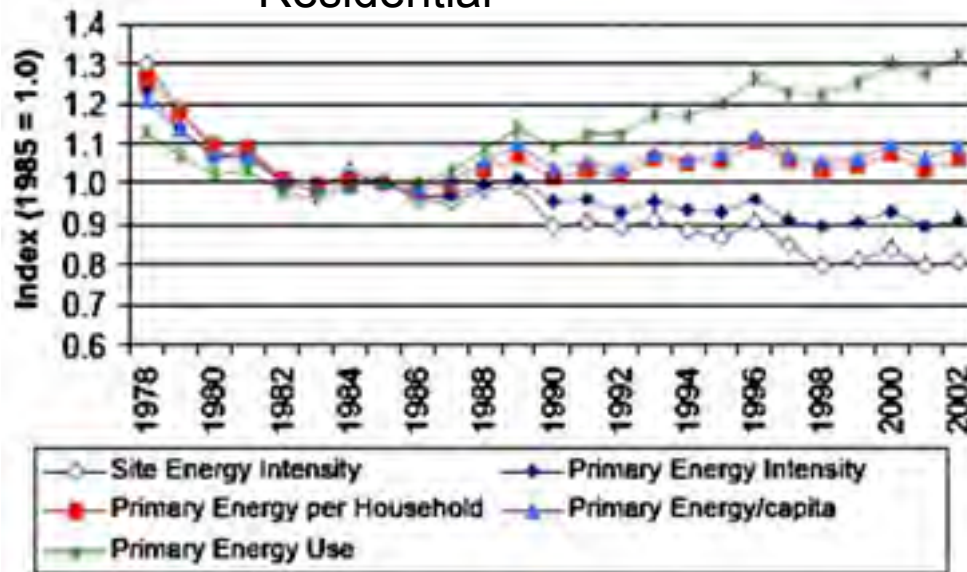
Behavioral science findings suggest ability of people to adapt and make changes in consumption, but circumstances are important.

Need to “scale up” behavioral science findings to broad classes of consumer activity, link them to potential policy changes, GHG reduction, assess impact on lifestyle.

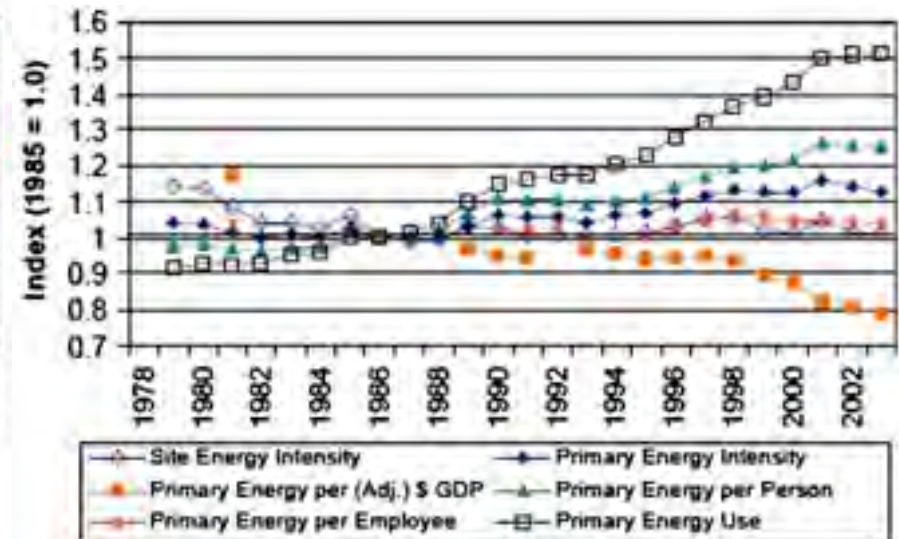
<sup>1</sup>US News and World Report, March 19, 2009

# Efficiency Paradox

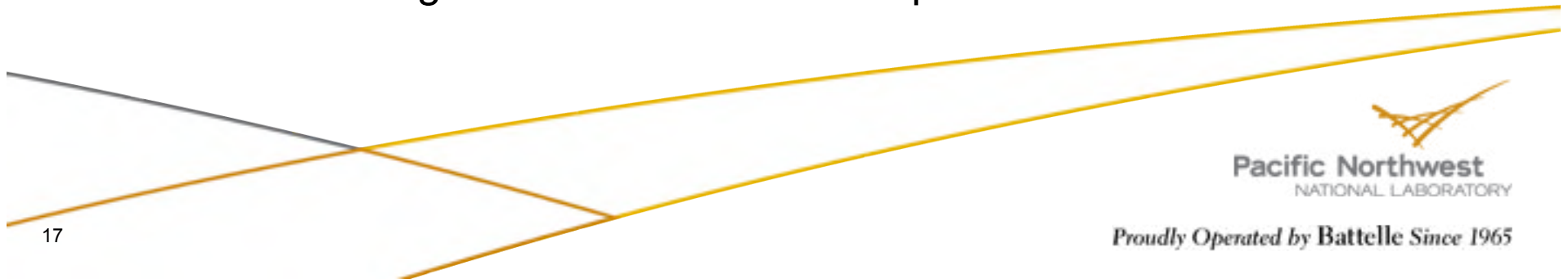
Residential



Commercial Building

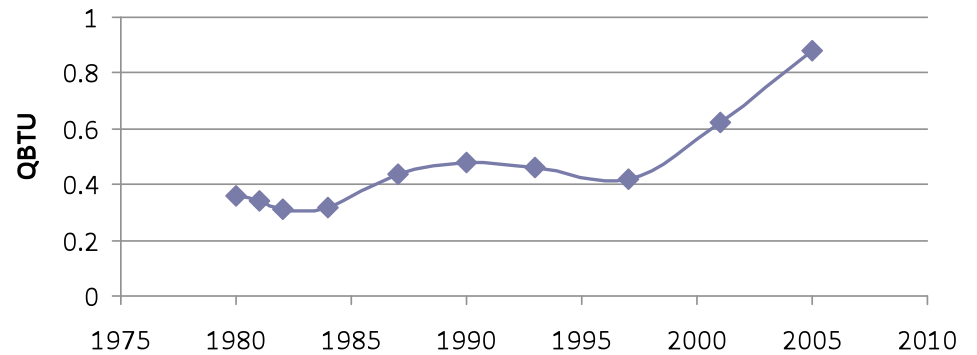


- ▶ Primary Usage increases vs. Intensity decreases illustrate “rebound effect” – savings in one area result in expenditures in another.

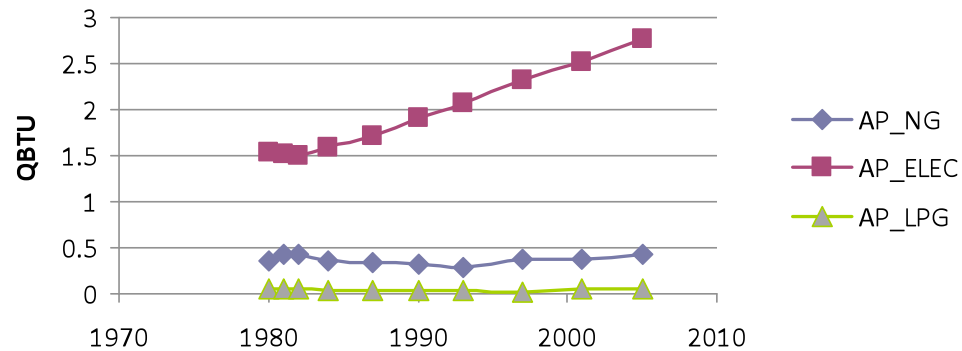


# Efficiency Paradox

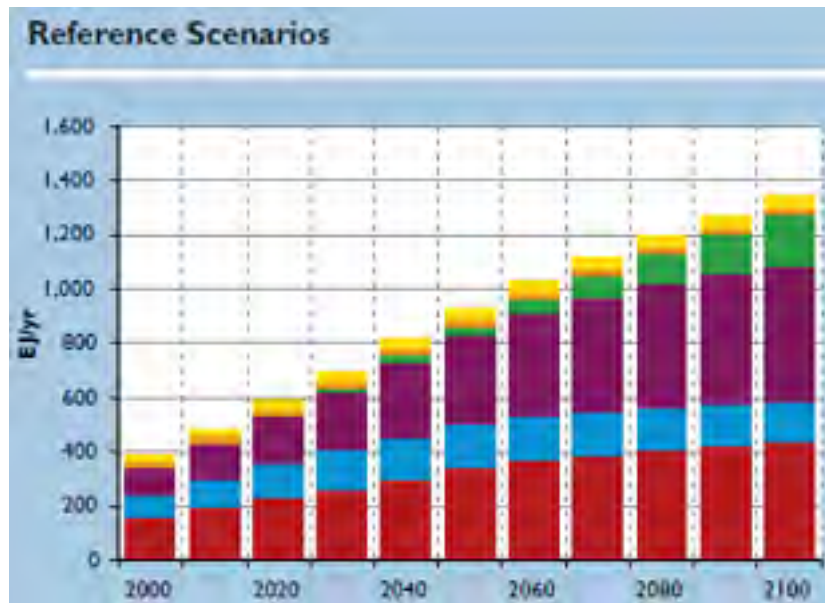
## Air Conditioning, 1980-2005



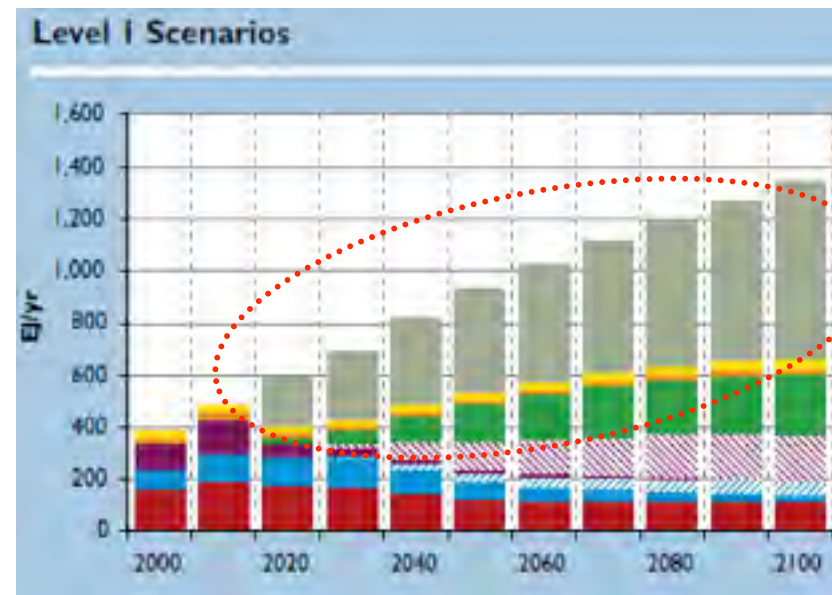
## Appliance Energy Use, 1980 - 2005



# Demand Reduction (efficiency and conservation) is a significant component of all climate models



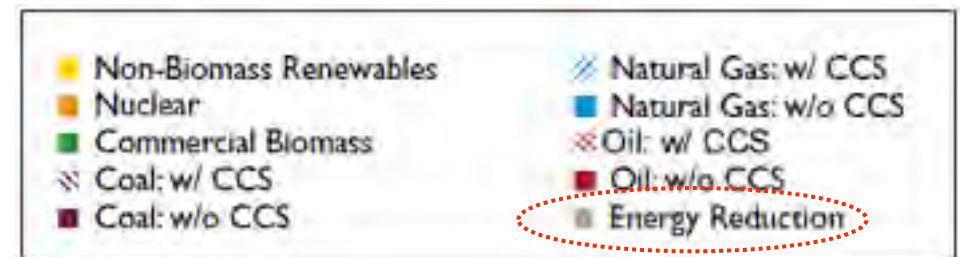
Global energy consumption  
by fuel type



The grey area:  
The role of behavior

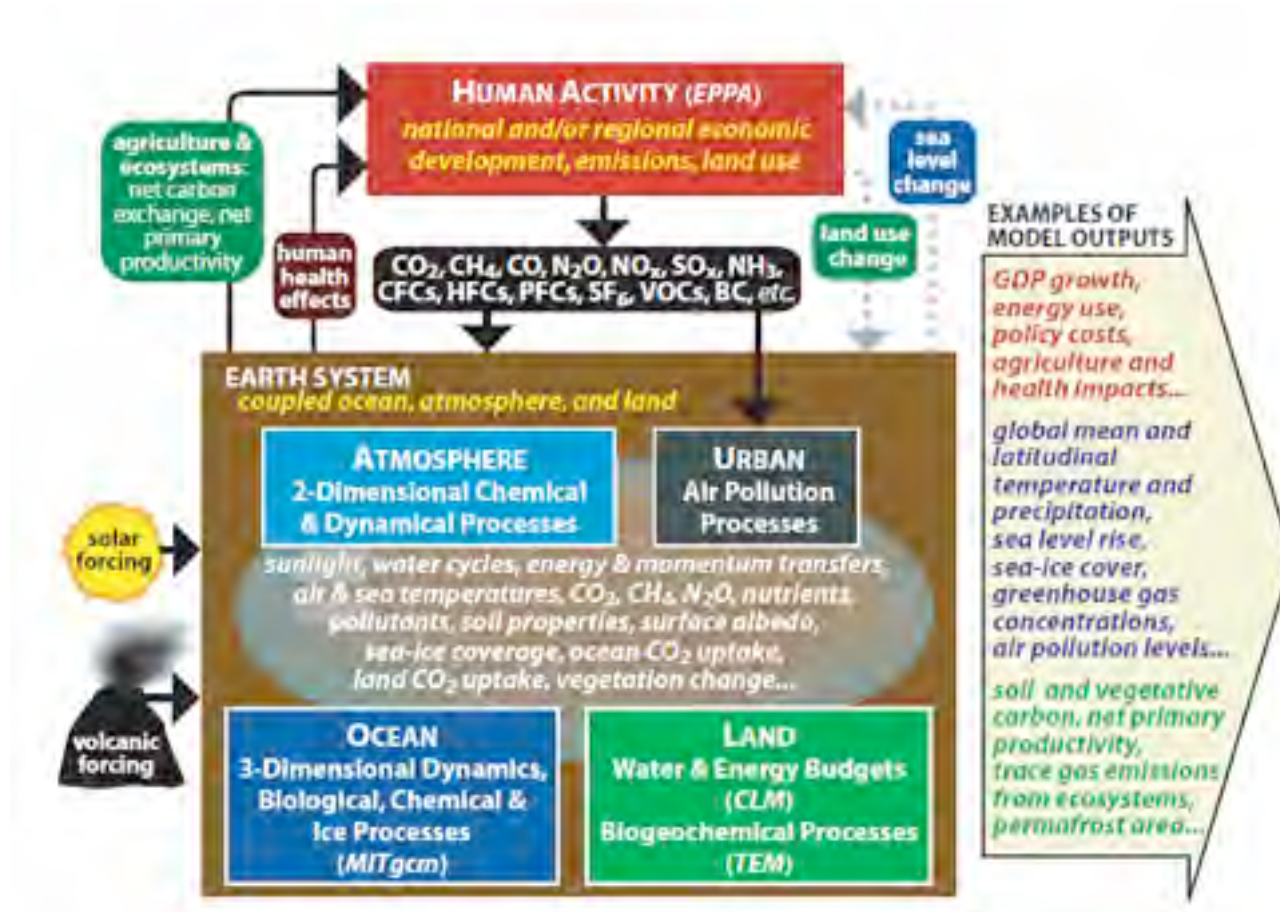
....Yet we know little about how it  
can be developed and sustained  
through behavior

19



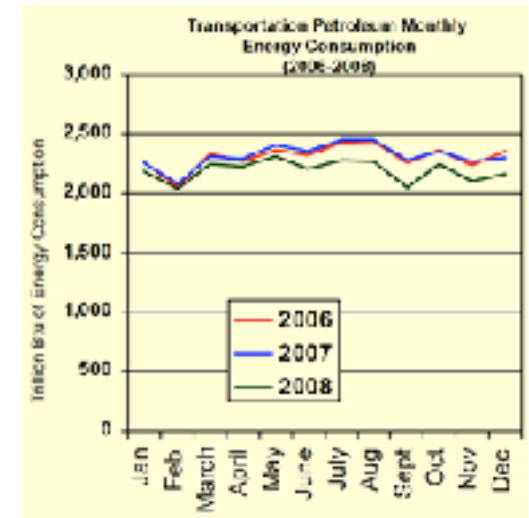
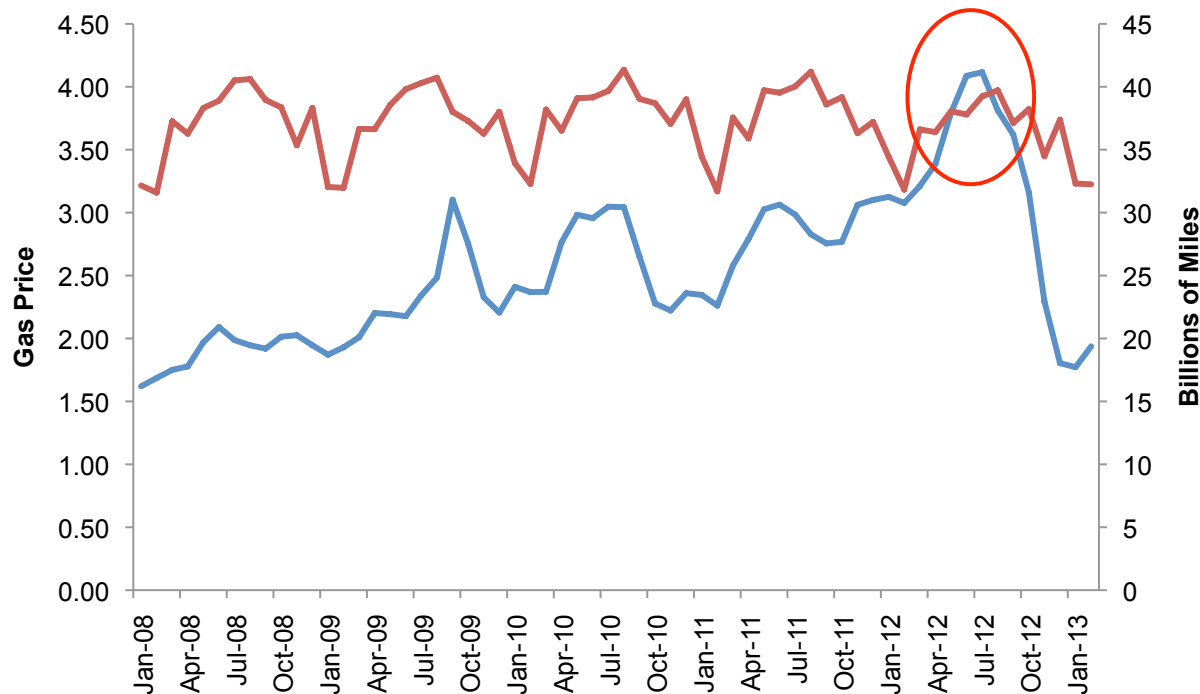


Climate models treat human behavior as an aggregate entity perfectly responsive to price signals (Homo Economicus), but yield only physical outputs



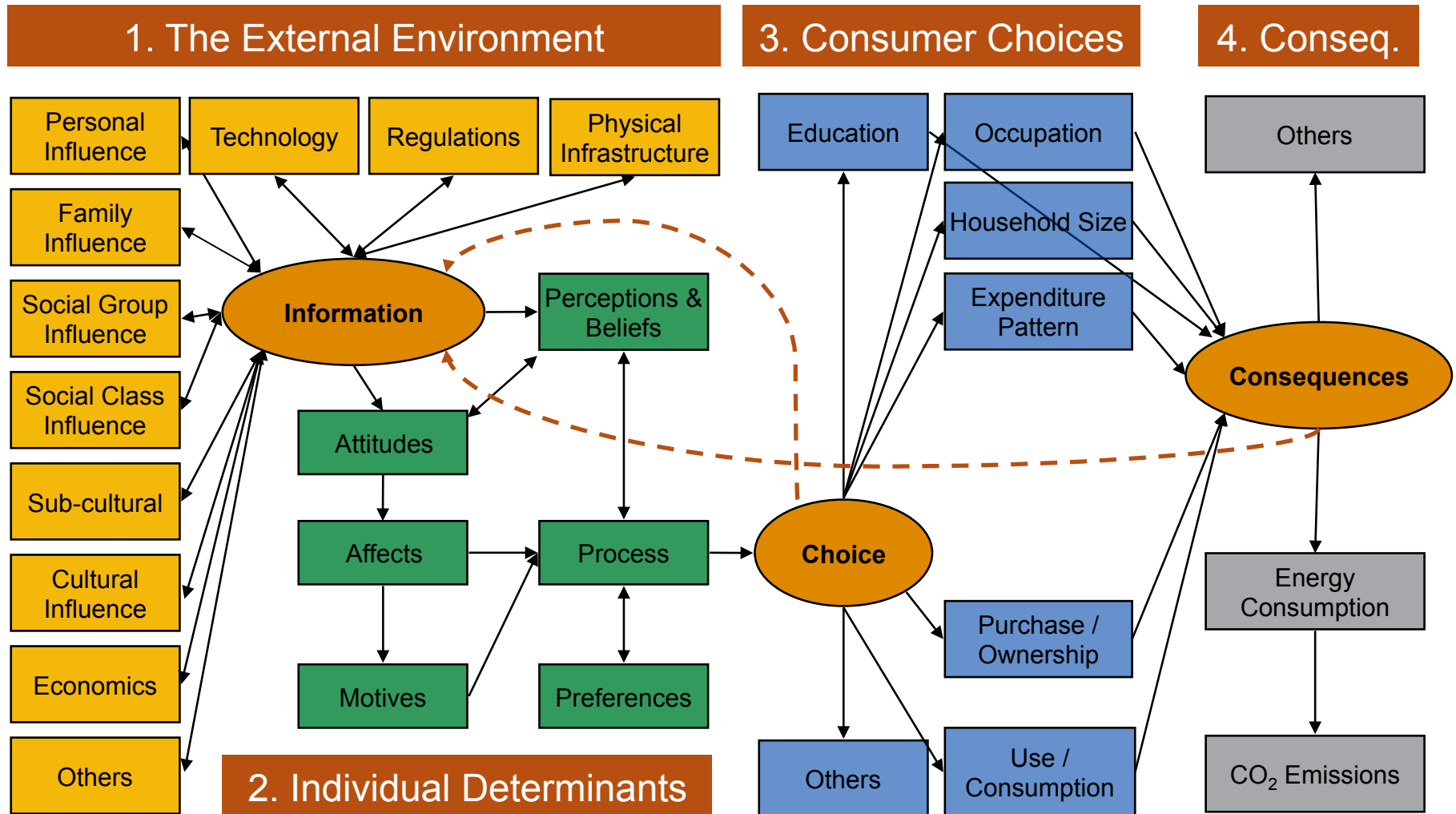
# Price Impact on Behavior – but there is more to behavior than price signals -

## Northeast Gas Prices vs Miles Driven



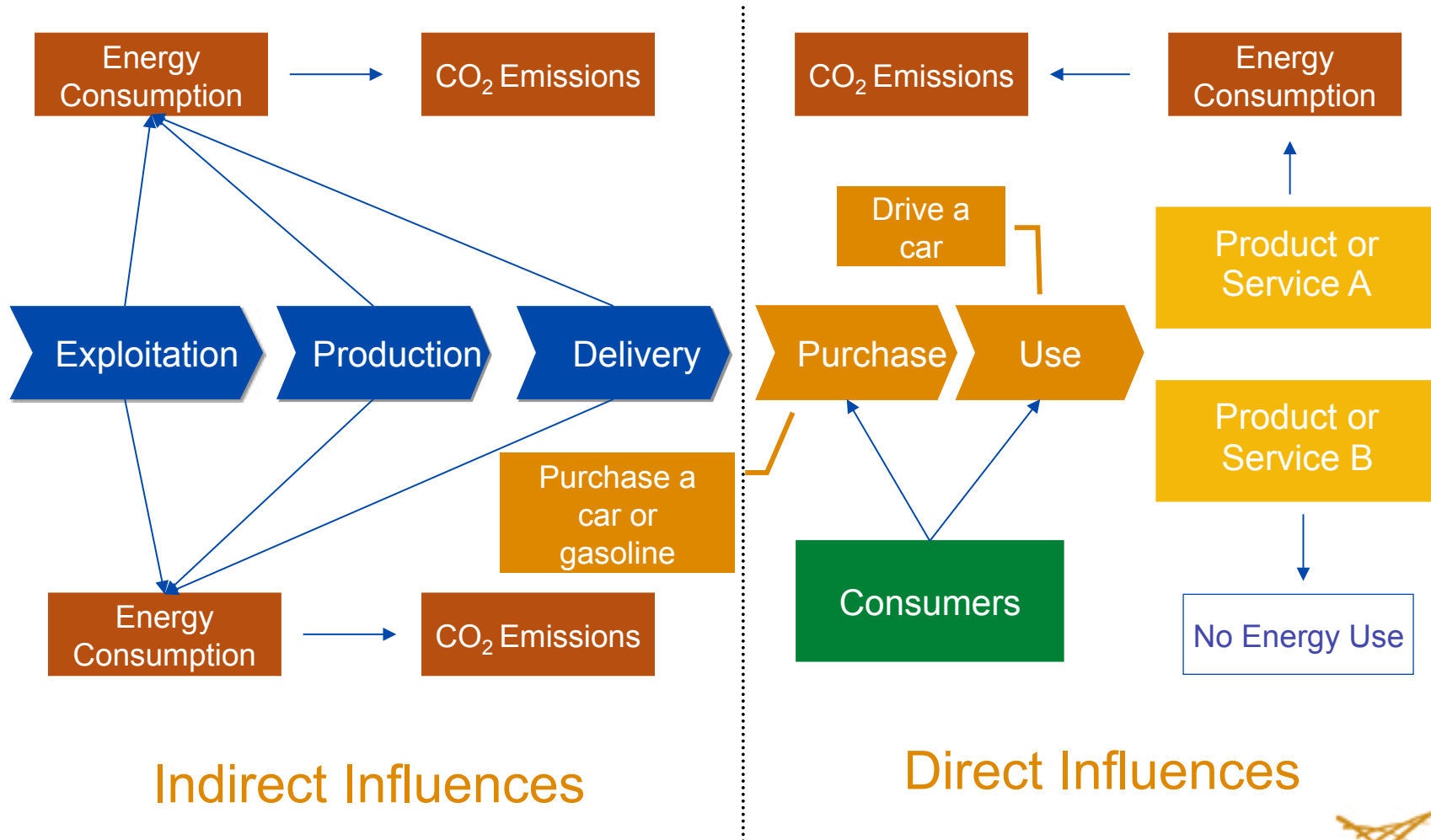
- Regular Unleaded Gas Price
- Miles Driven (in billions)

# Human Behavior and Environmental Consequences form a complex model





# Direct & Indirect Energy Consumption



# Methodology – Consumer Lifestyle Analysis

## ► Direct Influences – based on actual reading of energy use

### ■ Home Energy

$$HomeCO_2 = \sum_i \sum_j (Fuel_{ij} \times CO_2Coef_j \times 1000g)$$

### ■ Personal Travel

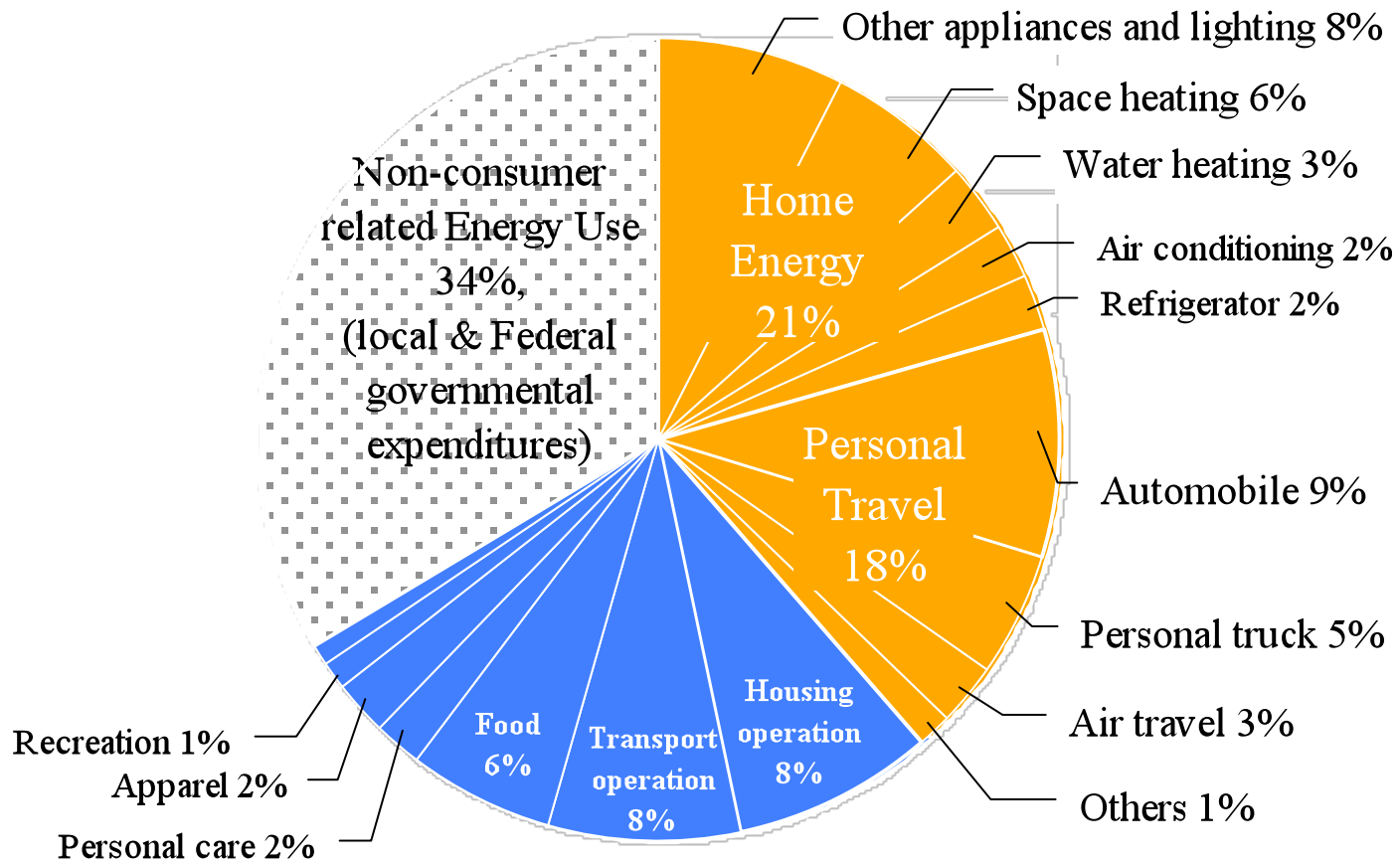
$$PTENERGY = \sum_j \sum_i (Fuel_{ij} \times DRatio_i \times VRatio_j)$$

## ► Indirect Influences – based on consumer expenditures and input-output model

$$X_i = \sum_j CES1997_j \frac{CPI1992_i}{CPI1997_j} \times T_{ji}$$

$$TINE_{input} = \sum_i (EI_i \times X_i)$$

# U.S. Energy Use Profiles in 2001

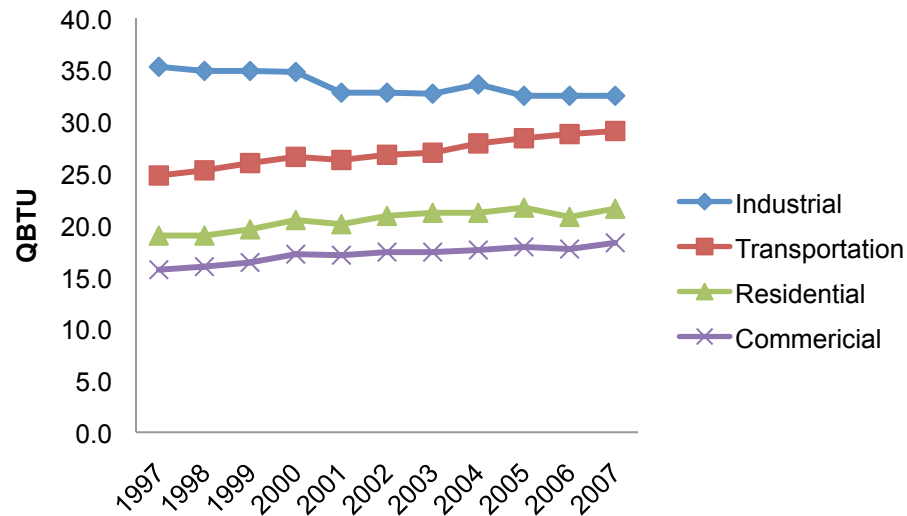


# Current Research

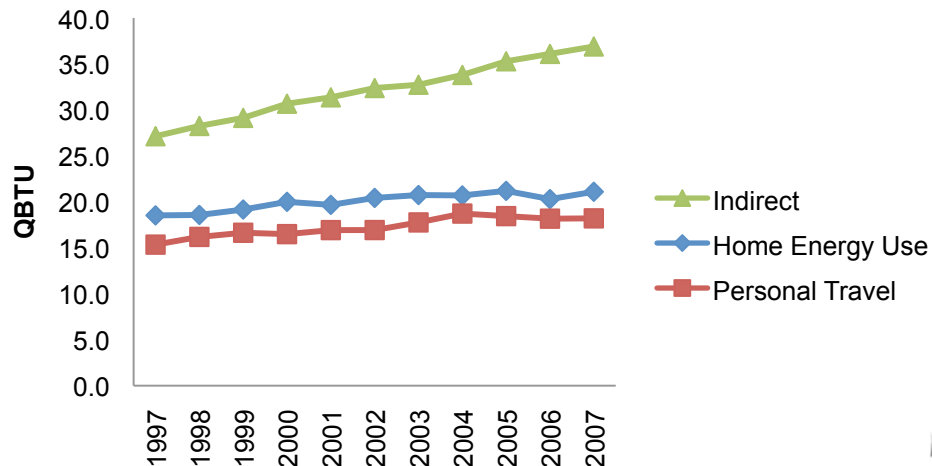
- ▶ Purpose: Over the LDRD period, adapt Consumer Lifestyle Analysis (CLA) energy/GHG modeling to technological and policy interventions, applying efficiency and conservation coefficients to evaluate impact
- ▶ Quarter 1
  - Review behavior/energy and climate modeling literature to determine potential for integration
  - Update CLA findings using new Residential Energy Consumption and Consumer Expenditure Survey databases (RECS), and ORNL databases for travel. Show baseline for 1997 – 2007.
  - Identify usage patterns and potential candidates for behavior change policies

# Consumer Lifestyle Analysis

**U.S. Energy Use by Sector, 1997-2007**

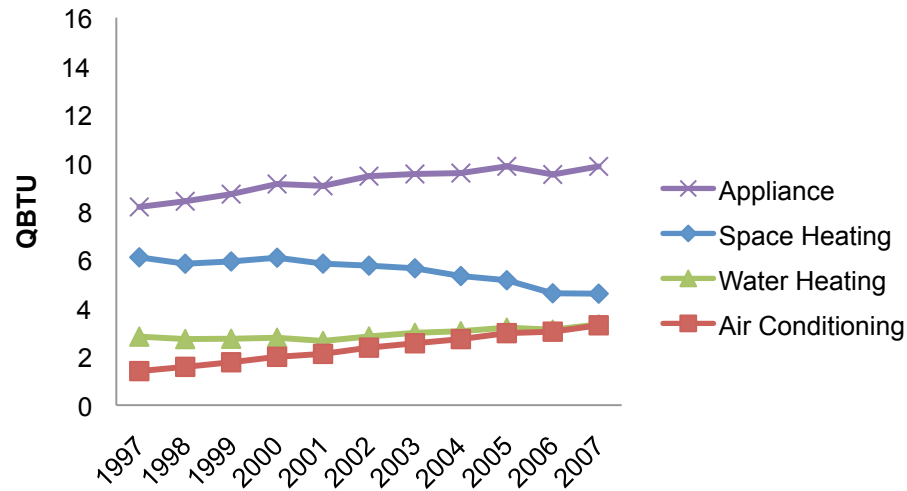


**U.S. Energy Use by Consumer Activity, 1997-2007**

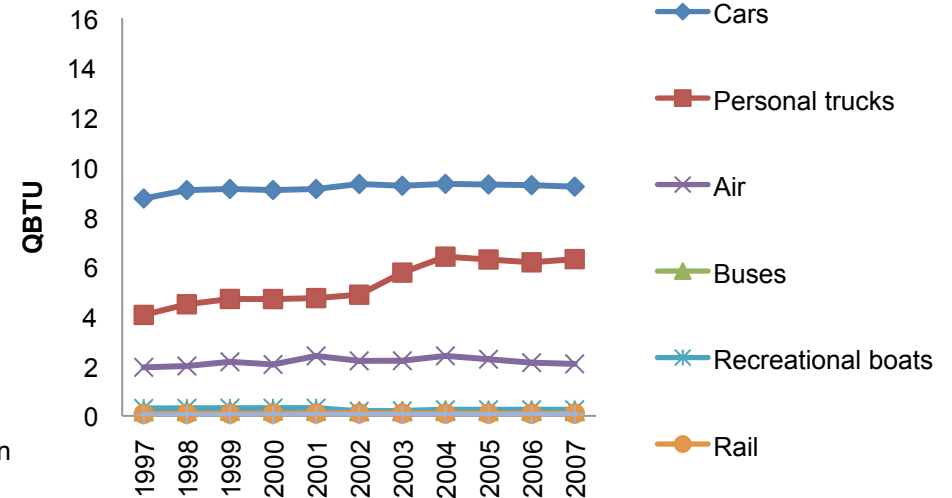


# Consumer Lifestyle Analysis

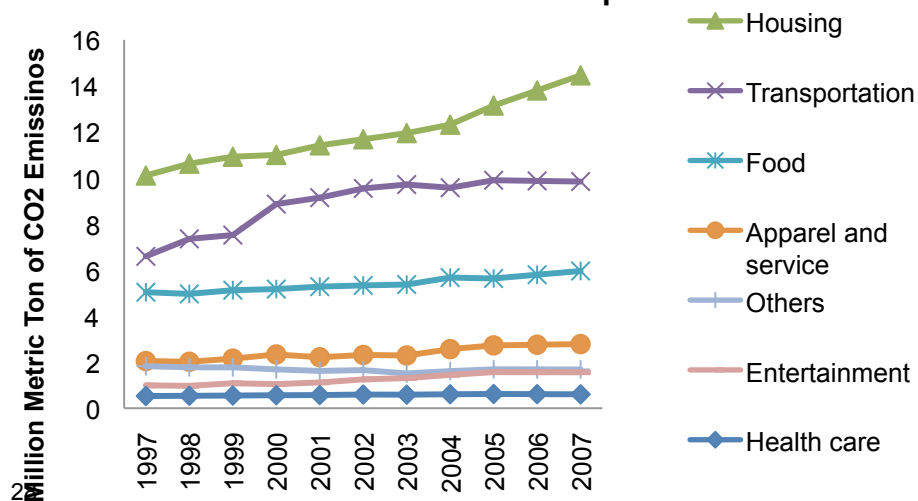
## Home Energy Use by Consumer Activity



## Energy Use of Personal Travel

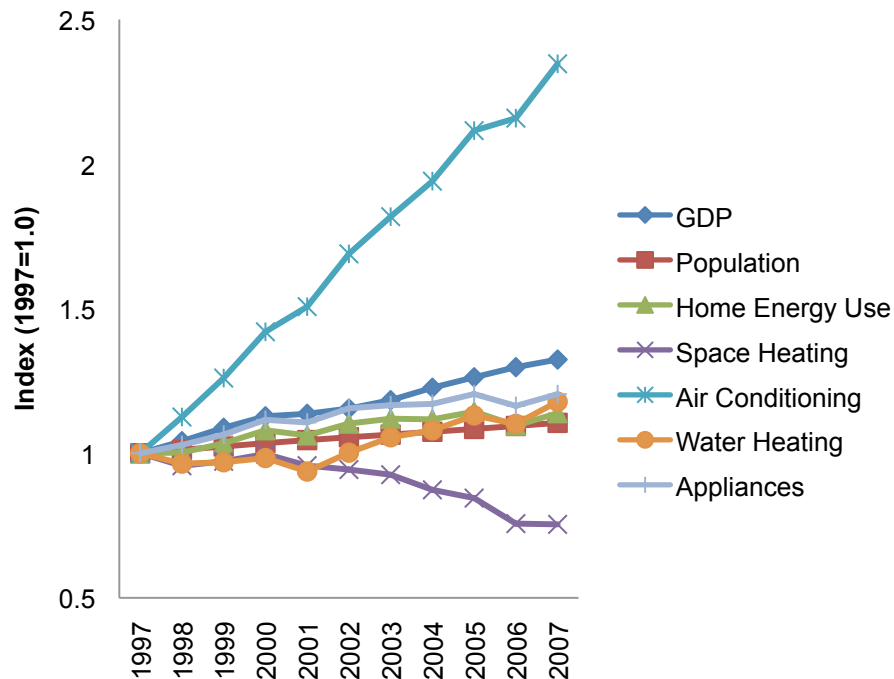


## Energy Use by Indirect Influences of Household Consumption

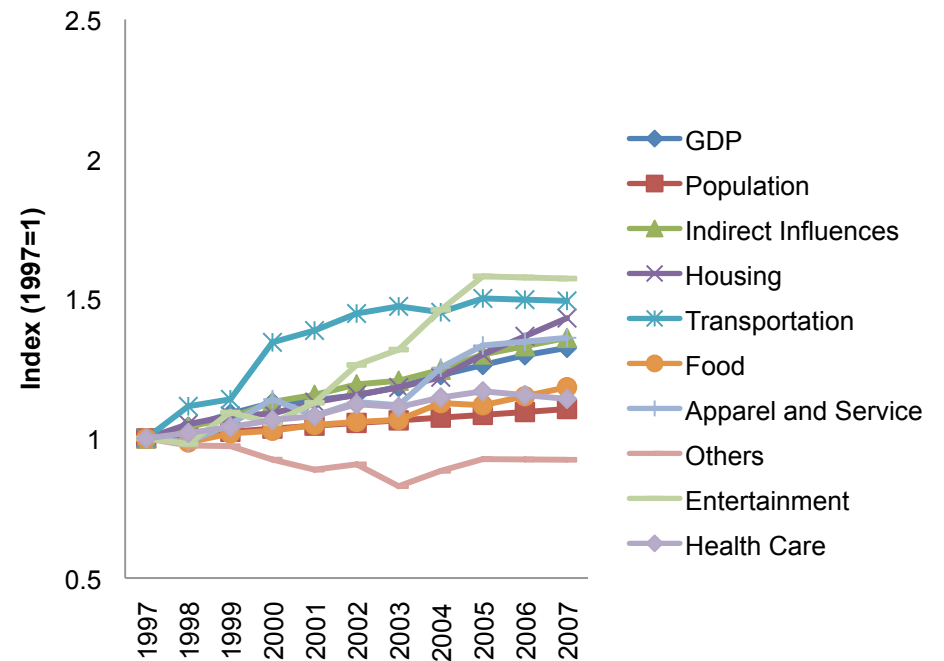


# Current Behavior: Growth Rates from 1997 to 2007

## Growth Rate of Home Energy Use

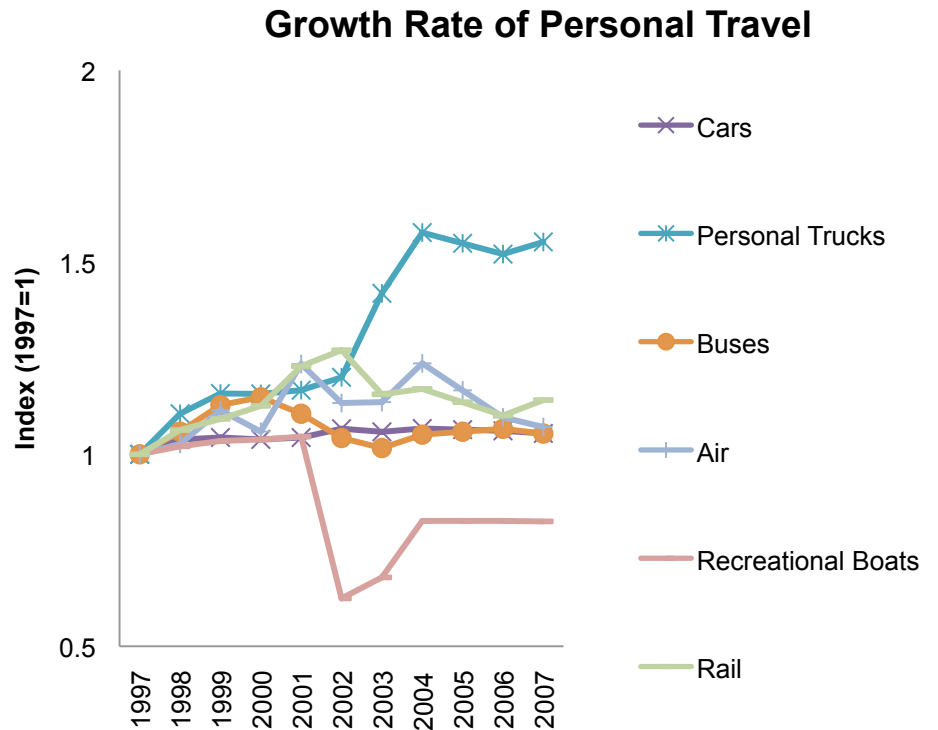
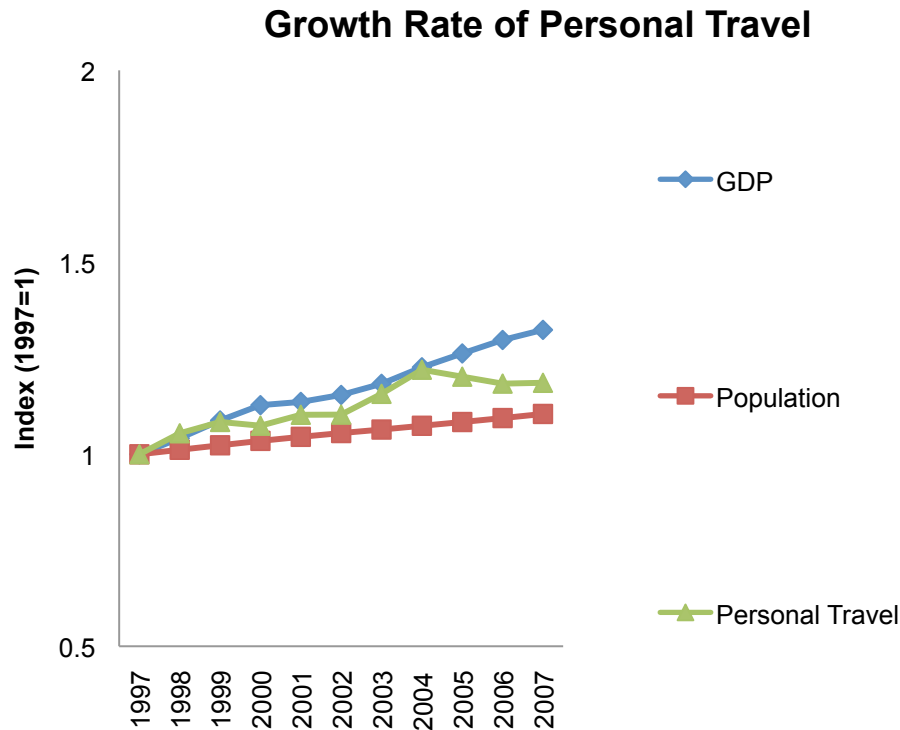


## Growth Rate of Indirect Influences



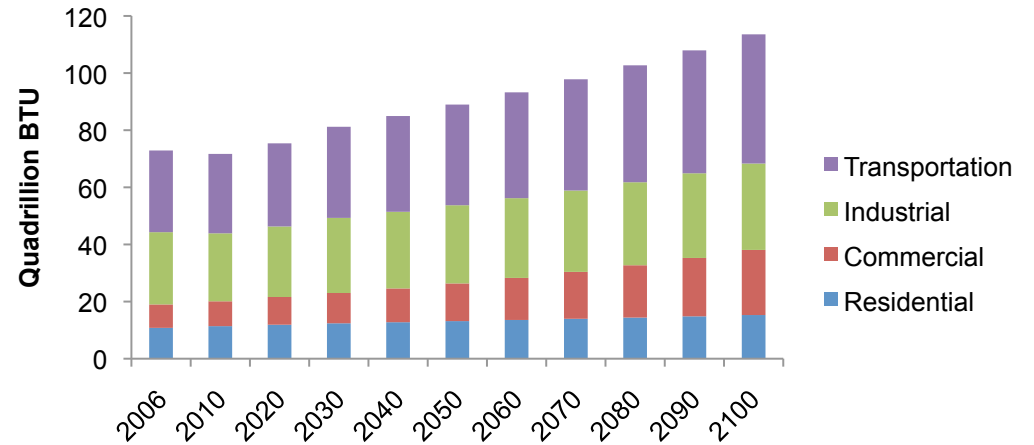


# Current Behavior: Growth Rates from 1997 to 2007

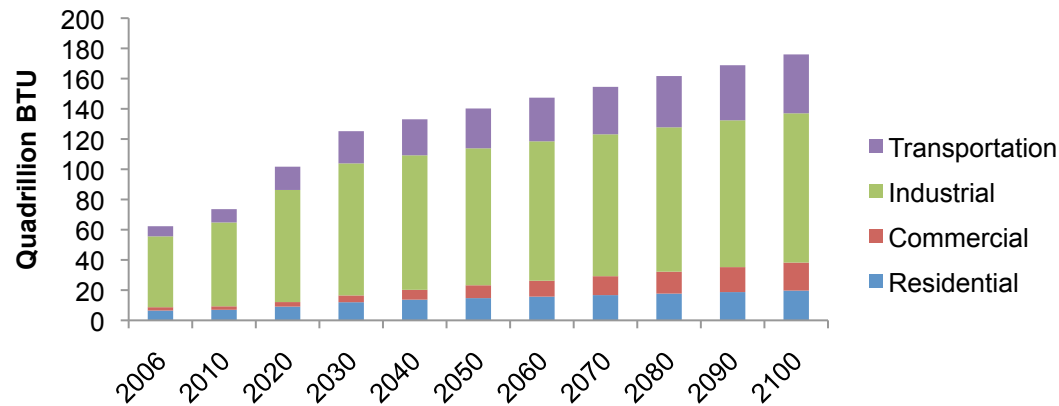


# Projected Energy Consumption

## US Energy Consumption 2006-2100

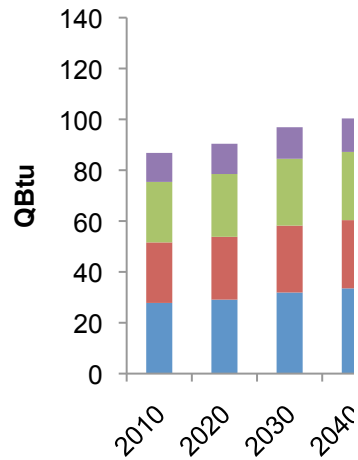


## China + India Energy Consumption 2006-2100



# Small Changes are not enough

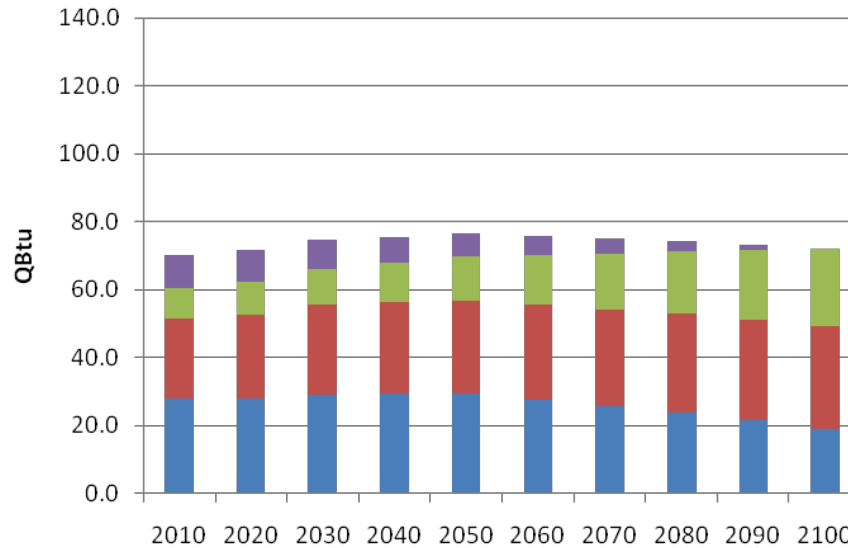
**Reference Case**



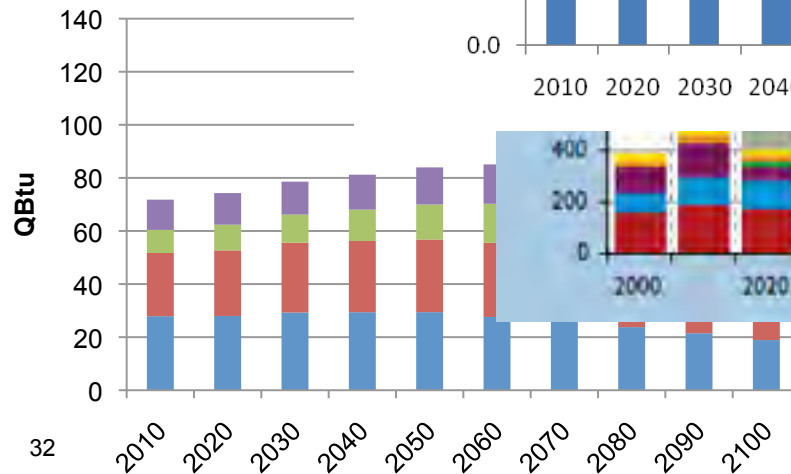
**Net Zero Houses Case**



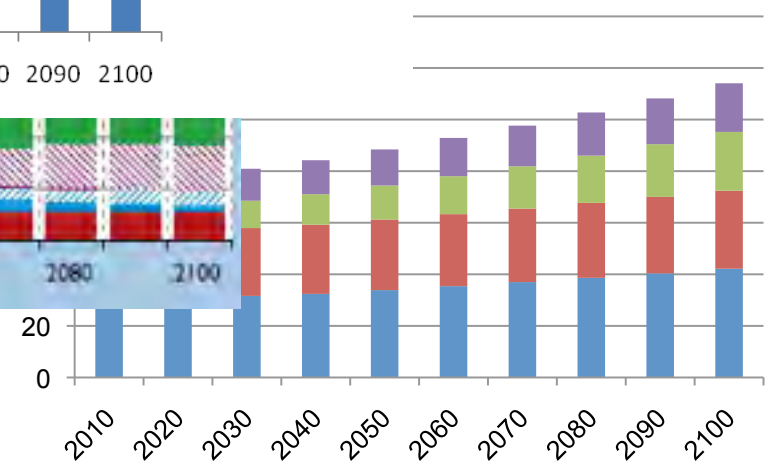
**Aggregate Case**



**Electr**



**Transportation Case**



# Examples Policy-Behavior-Energy Connections

## ► Where should I live?

- Land use planning policies at local level and lending practices at national level heavily influence development and subsequent transportation needs
- Past linkages between land use planners, developers, lenders and appliance manufacturers (A/C) has led to widespread development in environmentally unfriendly areas, and eliminated building practices using passive cooling. Federal lending standards encouraged this.

## ► Should I trade in my 9 year old 22 MPG car for a hybrid?

- Indirect energy costs associated with manufacture and disposal may outweigh life-cycle benefits of more efficient vehicle

# Specific Behavior-related energy impacts

- ▶ Selected curtailment and efficiency actions that can be taken by households to save energy (adapted from Gardner and Stern, 2008)
- ▶ Low-Cost Immediate Actions:
  - Transportation: carpooling, vehicle maintenance, good driving habits, combining trips, correct tire pressure.
    - **Energy Saved: up to 17.6%**
  - In home: Install fluorescent bulbs, heat to 68 (day) and 65 (night); cool to 78; caulk and weather strip.
    - **Energy Saved: up to 9.9 %**
- ▶ Higher-Cost, Longer-Term Actions:
  - Buy more fuel-efficient automobile (30.7 mpg vs. 20 mpg).
    - **Energy Saved: 13.5%**
  - Space conditioning – install or upgrade attic insulation/ventilation.
    - **Energy Saved: up to 7%**

# What does research tell us about behavior change? (after Paul Stern, 2008)

- ▶ Information and incentives are less effective than expected
- ▶ Effects vary considerably
- ▶ Strong influence of context (building structure, available technology, legal and regulatory requirements, convenience)
- ▶ Many behaviors are habitual; energy use is often “invisible”
- ▶ Individuals do not necessarily behave as economic maximizers
- ▶ Price increases often lead to suffering rather than investment in efficiency or behavior change



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# Behavior-related research needs

- ▶ Effect of “upstream” choices on consumer energy efficiency (and institutional-regulatory structure)
- ▶ Determinants of household choices among available homes and equipment
- ▶ Information delivery to consumers about options for improving efficiency and reducing carbon footprint
- ▶ How to make financial incentives more effective
- ▶ Market potential for fundamental design changes in built environment
- ▶ Better accounting for emissions reduction related to behavior



## Some behavioral tools

- ▶ Personal Carbon Allowances (UKERC)
- ▶ In-vehicle feedback on idling
- ▶ Community-based social marketing
- ▶ Comparative feedback on utility bills
- ▶ Car sharing
- ▶ Progressive efficiency
- ▶ Sufficiency policies
- ▶ Work hours & telecommute
- ▶ Urban planning & re-design
- ▶ ???

# International Comparative Studies

## ▶ US Study:

- Consumer lifestyle approach to US energy use and the related CO<sub>2</sub> emissions
- Shui Bin, Hadi Dowlatabadi
- Energy Policy 33 (2005) 197–208



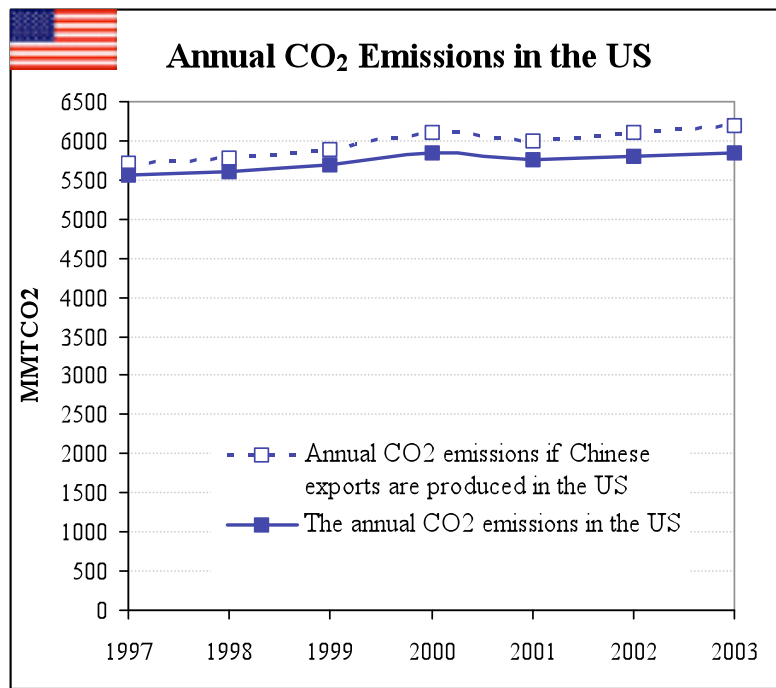
## ▶ China Study:

- The impact of lifestyle on energy use and CO<sub>2</sub> emission: An empirical analysis of China's residents
- Y-Ming Wei, Lan-Cui Liu, Ying Fan, Gang Wu
- Energy Policy 35 (2007) 247-257

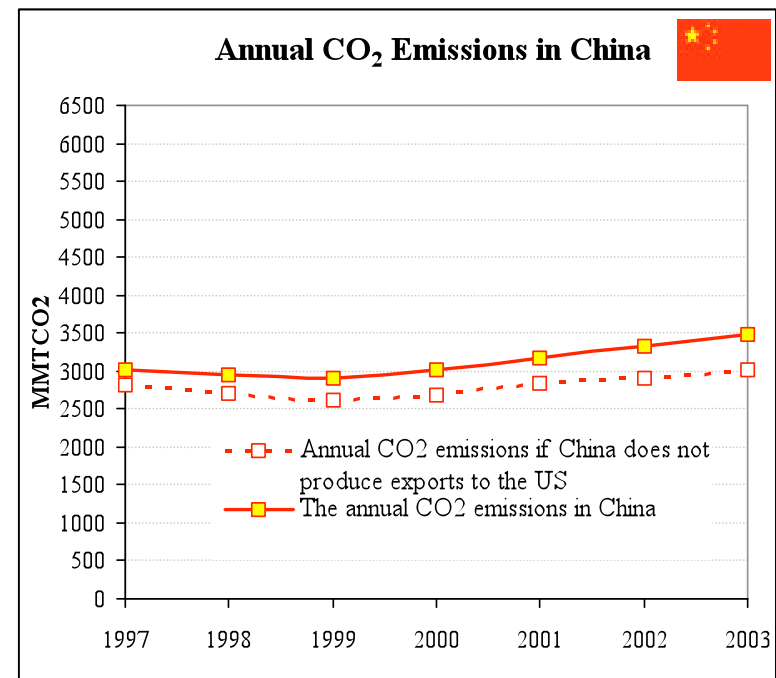


# US-China Trade

The US shifts its responsible CO<sub>2</sub> emissions, mainly driven by its final consumption, to China through its huge imports.



The CO<sub>2</sub> emissions in the US would be 3% (in 1997, 1998) to 6% (in 2003) higher than the current level.



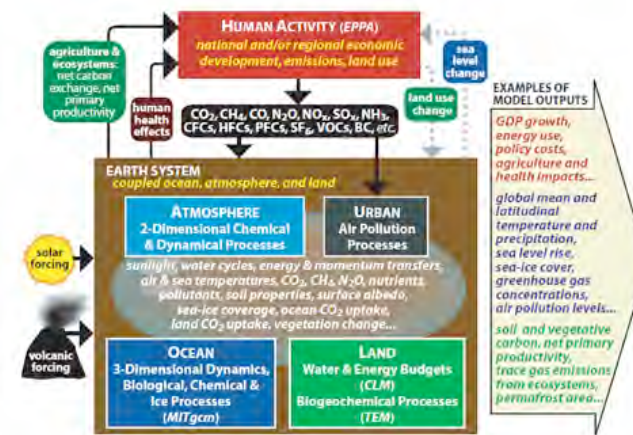
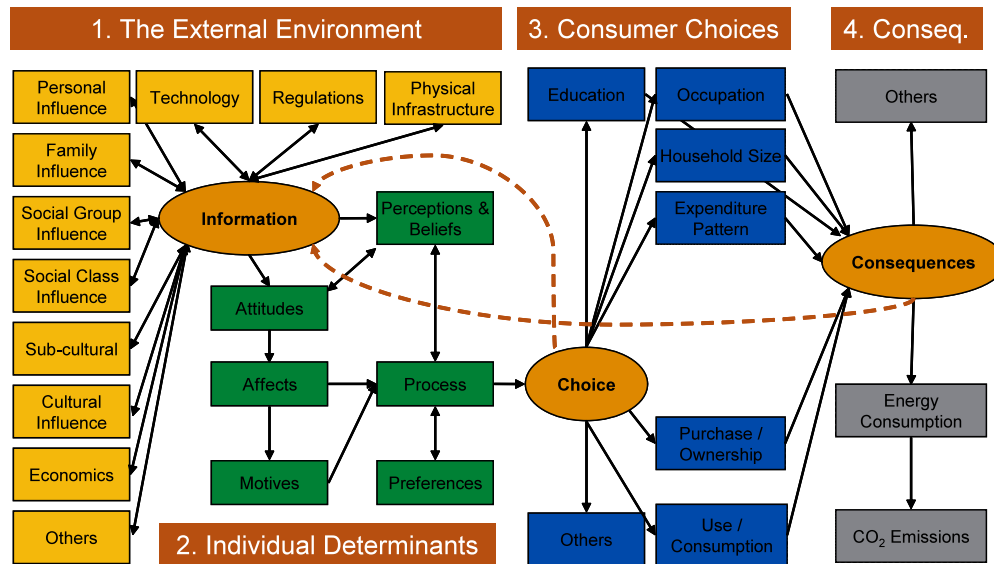
About 7% (in 1997) to 14% (in 2003) of China's annual CO<sub>2</sub> emissions is from producing exports to the US.

*Shui & Harriss (2006)*

# Future Work

- ▶ Goals: (1) establish an empirically-based model of behavior-energy-climate impact relationships, and (2) to apply to evolving policy interventions aimed at reducing greenhouse gas domestically (e.g., Waxman-Markey).
- ▶ Tasks
  - Detailed specification of “energy use reduction” factors from climate models and behavioral literature
  - Address “rebound effect”
  - Efficiency vs. conservation gaps
  - Behavioral scenarios for conservation over time
  - Common model to parameterize behavior in terms of GHG reduction compared to targets.
  - Comparative analysis (China & US)

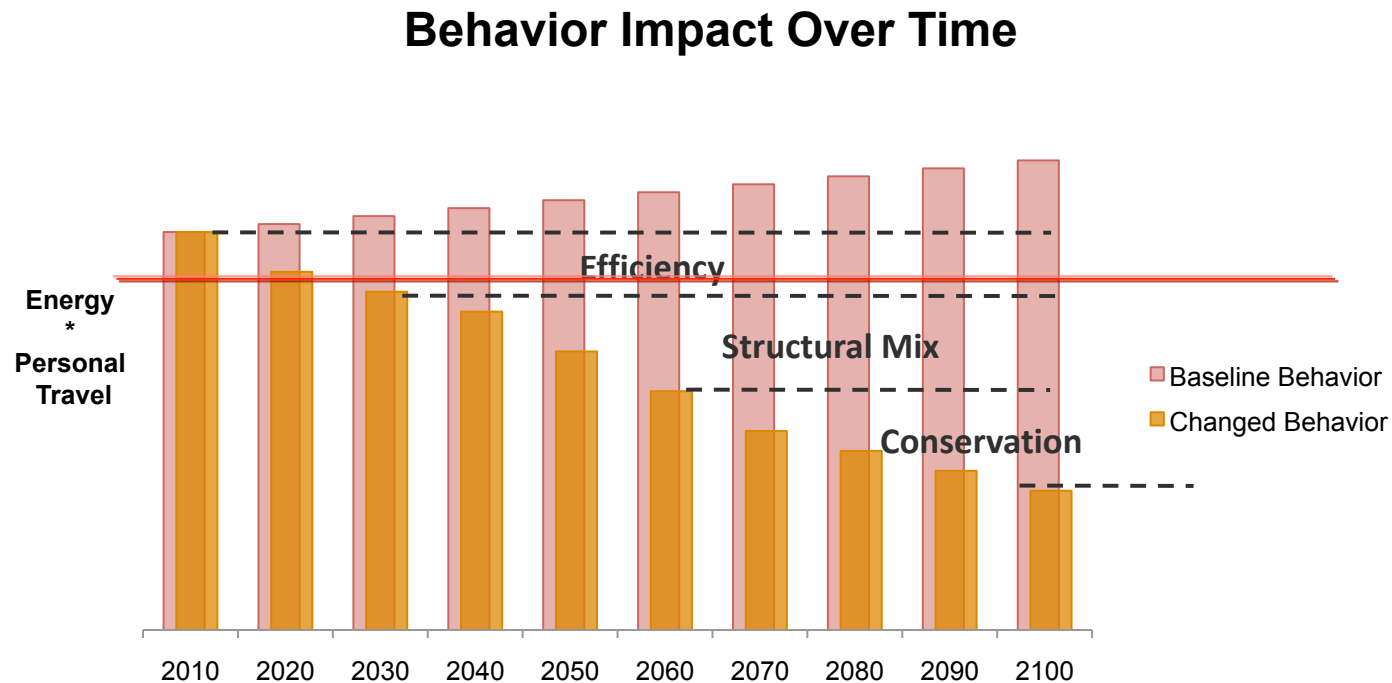
# Integration of behavioral & climate models



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# Behavior Change Prediction



- ▶ Develop engineering model of relationships between GHG reduction, policy options, behavioral & social effects
- ▶ Quantify the “social-behavioral wedge”



# Thank You!

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206-528-3240  
[sanquist@pnl.gov](mailto:sanquist@pnl.gov)



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# Extras



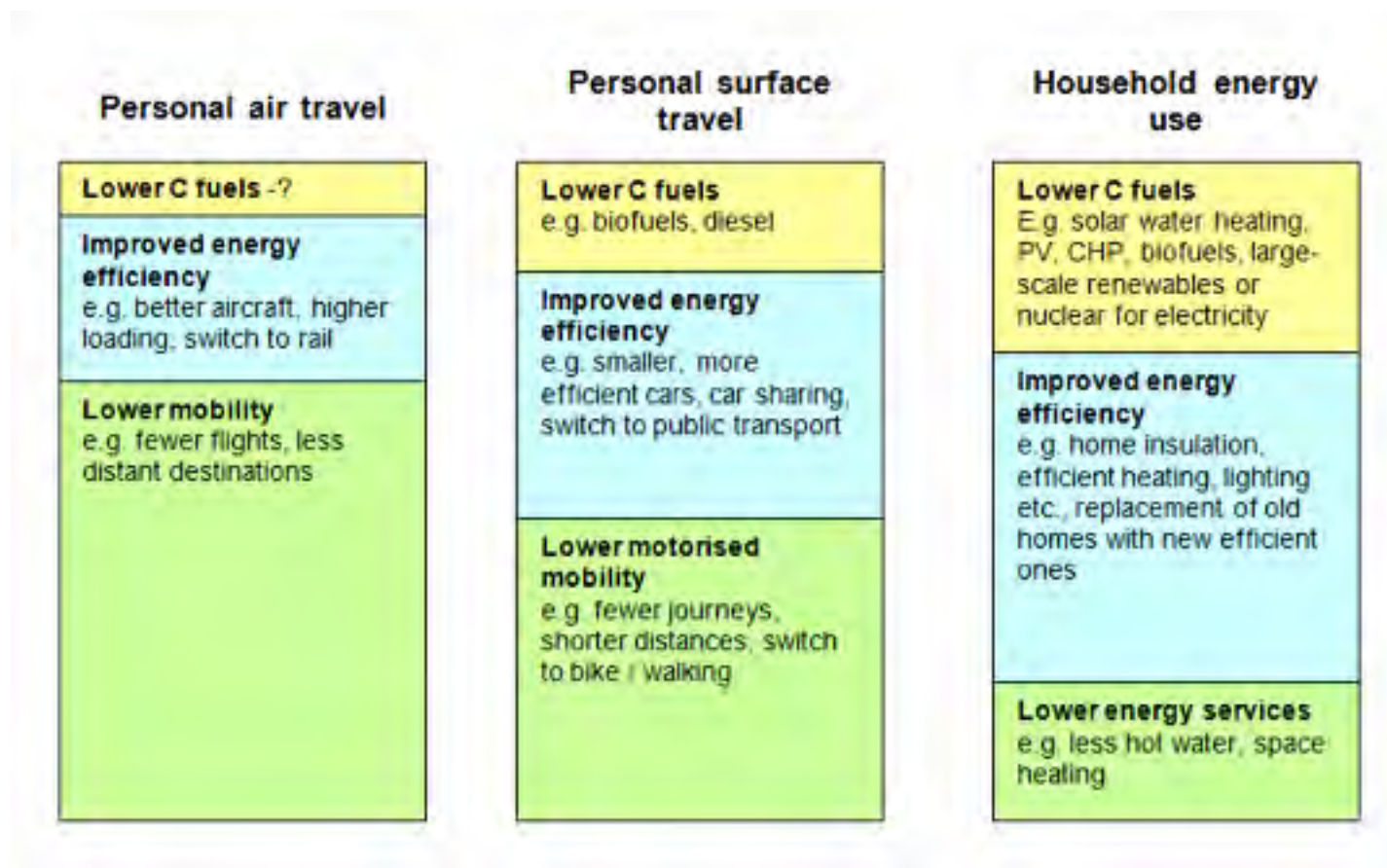
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## Changes in carbon emissions between 1990 and 2003 (UKERC & ECI)

	Personal air travel	Personal surface travel	Household energy use
<b>C emissions 1990 onwards</b>	 C emissions from international air travel increase 85% 1990-2002	 C emissions from road transport increase 10.5% 1990-2001	 C emissions decrease only 0.5% 1990-2001
<b>Lower carbon fuels</b>	 No change	 Switch to diesel in cars gives lower C/km	 Lower C electricity & greater use of gas
<b>Energy efficiency</b>	 Continuing historical improvement trend.	 Vehicle efficiency new cars improved   Journeys less efficient, higher car usage, lower car occupancy.	 Building shell and equipment more efficient
<b>Mobility / energy services</b>	 Distance travelled per person per year increasing rapidly	 Total passenger distance travelled up 15% 1990-2003.	 Increase in household numbers, higher internal temperatures, more ownership of electrical goods etc.

## Relative contribution to achieving 60% carbon savings by 2050 Personal air travel (UKERC & ECI)



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# Efficiency and sufficiency

Energy Service	Efficiency Considerations	Sufficiency Considerations
Driving	MPG	Travel or not? How much to travel? What mode of travel?
Space Heating	Energy delivered/m <sup>2</sup> floor area	Amount of living space; household size; acceptable temperatures
Food refrigeration	Delivered energy/m <sup>3</sup> chilled space	Is refrigeration necessary? How much cooled space?